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# INVESTIGATION OF ACOUSTIC EMISSION SIGNAL GENERATED IN THE FRICTION PAIR LUBRICATED WITH OILS CONTAINING VARIOUS LUBRICITY ADDITIVES

J. Guzik[1)], M Wojtyniak[1)], S. Olszowski[1)], M. Marczak[1)], Z. Ranachowski[2)]

[1)] **Technical University of Radom**
**Institute of Maintenance of Machines and Vehicles**
Chrobrego 45, 26-600 Radom, Poland

[2)] **Institute of Fundamental Technological Research**
**Polish Academy of Sciences**
Świętokrzyska 21, 00-049 Warszawa, Poland

The energy supplied to the friction pair is dissipated producing mainly heat. However, a small part of it radiates in the form of transient elastic waves or in other words, as the acoustic emission (AE) signal. This article presents measurement results of the AE signal generated in the four-ball friction pair lubricated with oil containing chosen lubricity additives. Measurements of the AE signal have been performed in conditions of continuous load increase. Values of friction torque in the pair were recorded simultaneously with AE measurements. It is expected that diagnostic measurements of AE signal generated in friction pairs of working machinery will be possible soon.

**Key words:** friction torque, acoustic emission (AE) signal.

## 1. Introduction

Phenomena occurring in friction pairs cause in effect, among others, dissipation of the supplied energy. A very small amount of energy is emitted as an acoustic emission (AE) signal. As a rule, friction pairs emit acoustic energy in a wide frequency range, also at relatively high frequency values.

High sensitivity accelerometers or sensors transmitting AE spectrum in the whole frequency range are required to measure AE signals emitted in friction pairs. Transmission conditions of an AE spectrum to the computer are also very important. Proper transmission requires high quality instrumentation and computer software. Block diagram of an AE equipment to record signals generated in friction machines is presented in Fig. 1.

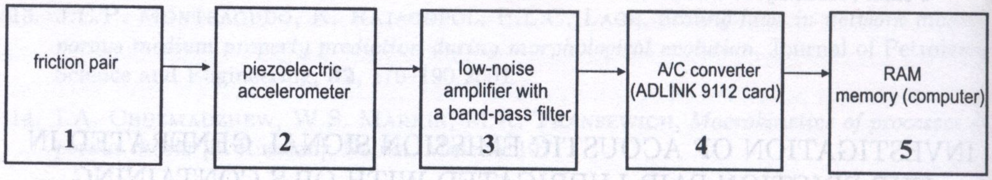



FIG. 1. Block diagram of an AE equipment to record signals generated in a friction machine.

Mass production of instrumentation for vibration monitoring in the field of machine diagnostics has been initiated in 1943 by Brüel and Kjaer, after development of a sensor – the fist in the world piezoelectric vibration accelerometer [1].

Authors of this work applied in the presented tribological investigations an accelerometer model 4371 manufactured by Brüel and Kjaer, having the frequency response of 0.1 – 42 kHz (No. 2 in Fig 1). Computer program developed in 2003 by Z. RANACHOWSKI (co-author of the paper [5]), allows to record every 2.5 seconds the temporary power of the signal generated by kinematic systems [5]. Z. Ranachowski has also designed and tested a low noise amplifier with a band-pass filter (No. 3 in Fig. 1). Application of a low-noise amplifier with exactly determined band-pass filter guarantees optimal separation of the investigated acoustic emission signal from other sources. The described amplifier is equipped with integrated circuits of type LT1028 and has the frequency range of 0.6–40 kHz.

An essential element of the AE signal registration equipment is the A/C converter allowing to record the registered signal in computer memory. The authors have compared operational parameters of various converters choosing in effect the ADlink 9112 card (No. 4 in Fig. 1).

Simultaneously with registration of the AE signal generated in friction pairs, tribological characteristics (friction torque) for known tribological enforcements at lubrication with model oils were investigated. Knowledge of correlation between the tribological characteristics and AE signal could be used in future to evaluate the tribological properties of friction pairs in working machines on the basis of direct AE measurement.

## 2. INSTRUMENTATION AND INVESTIGATION METHODS

A cross-section of an accelerometer applied in the investigations and its frequency response are presented in Fig. 2.

The accelerometer was mechanically connected (by a screw) with a stationary balls holder in the four-ball apparatus. The friction pair was lubricated with reference oil RL 144/4 without additives and the same oil containing anti-wear

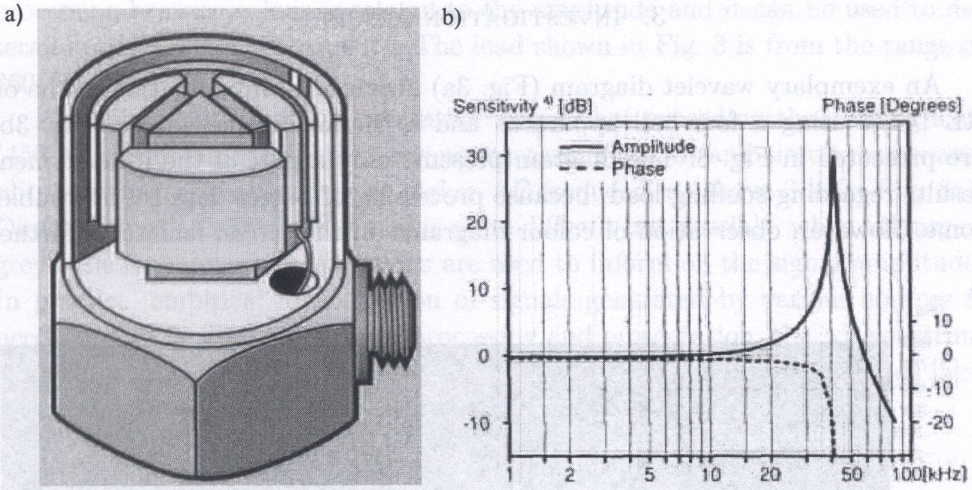



FIG. 2. A cross-section a) of the Brüel and Kjaer accelerometer type 4371 and its frequency response b). Test signal of acceleration of 1 g in the working area of the sensor generates the 8 mV RMS signal at the sensor output.

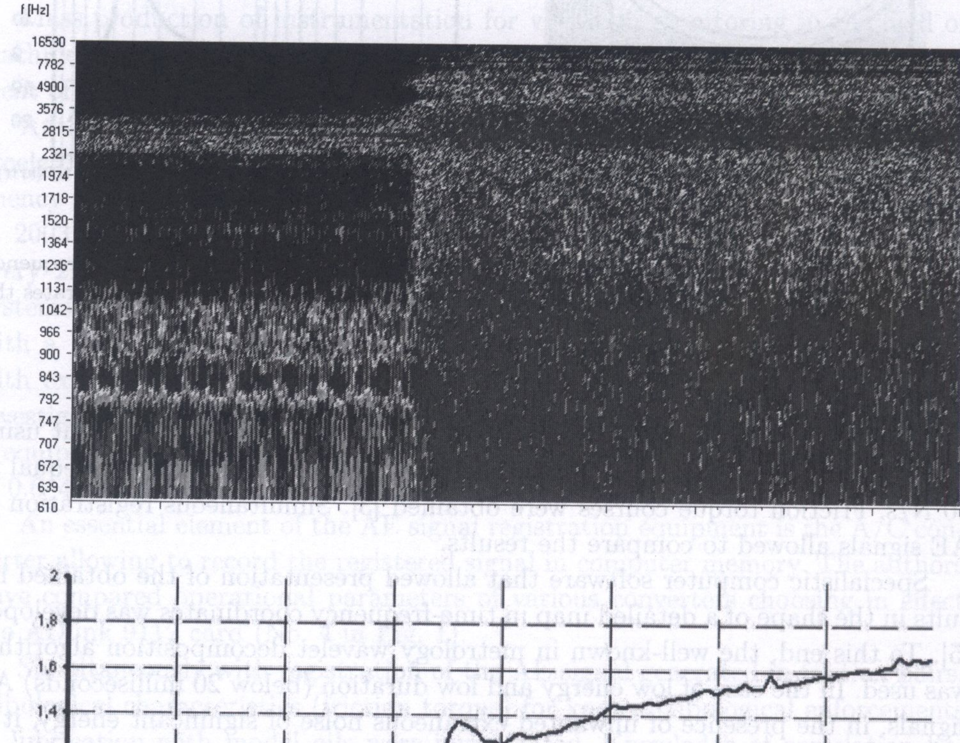
(AW) or extreme pressure (EP) additives. Investigations were carried out using a modified four-ball apparatus at the speed of continuous load increase equal to 40 N/s. Friction torque courses were obtained [3]. Simultaneous registration of AE signals allowed to compare the results.

Specialistic computer software that allowed presentation of the obtained results in the shape of a detailed map in time-frequency coordinates was developed [5]. To this end, the well-known in metrology wavelet decomposition algorithm was used. In the case of low energy and low duration (below 20 milliseconds) AE signals, in the presence of unwanted extraneous noise of significant energy, it is not possible to reconstruct effectively the spectrum characteristic of these signals applying standard methods like time characteristic monitoring with active band-pass filters or applying discrete Fourier transformation, because it requires analyzis of too many non-zero signal samples. Analysis of short impulses needs the assumption that resultant time-frequency characteristic of the analysed signal will be determined with lower precision (by time intervals) than that in the case of application of the above-presented methods individually, i.e. the time-frequency characteristic and spectrum characteristic of a more numerous set of analysed signal samples. In the presented investigation, the wavelet decomposition method was applied. This method gives better information on the changes occurring in time than the Fourier transformation, what is important in the case of acoustic emission signal analysis [4].

## 3. Investigation results

An exemplary wavelet diagram (Fig. 3a) obtained in investigation in the oil RL 144/4 using a four-ball apparatus and a friction torque course (Fig. 3b) are presented in Fig. 3. The diagram presents only a part of the measurement results regarding scuffing load, because processing of bigger data set is troublesome. However, observation of colour diagrams on the screen facilitates further

a)




b)

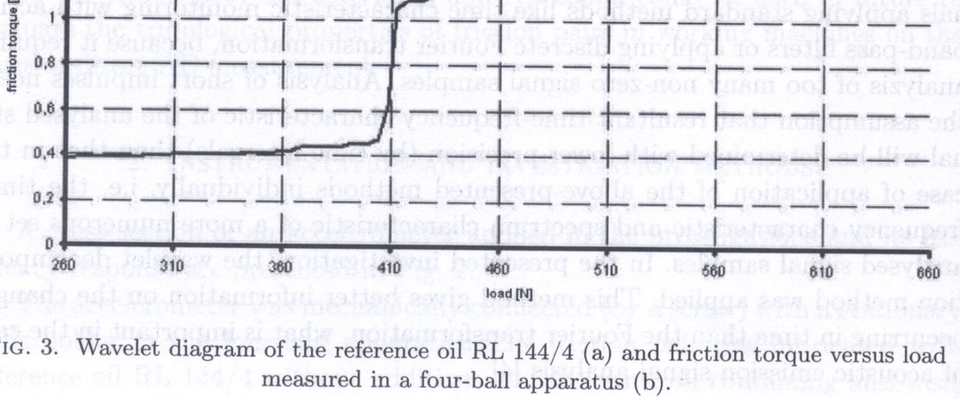



FIG. 3. Wavelet diagram of the reference oil RL 144/4 (a) and friction torque versus load measured in a four-ball apparatus (b).

processing because colour is related to the amplitude and it can be used to determine the AE signal frequency. The load shown in Fig. 3 is from the range of 260–660 N.

Analysing the Fig. 3 one can easily notice that exceeding the scuffing load (450 N) causes sudden friction torque increase (Fig. 3b) and simultaneous amplitude increase, particularly at higher AE frequencies (above 3 kHz; Fig. 3a). Direct evaluation of the AE signal is quite difficult but possible, when colours or grey scale for monochrome systems are used to inform on the signal amplitude. In practice, empirical identification of signals generated by various sources is necessary. To facilitate the result processing and presentation, the AE spectrum was divided, using computer programs, into the following frequency bands [5]:

| | | |
|---|---|---|
| band 1 | from 0.5 kHz | to 0.55 kHz, |
| band 2 | from 0.55 kHz | to 0.65 kHz, |
| band 3 | from 0.65 kHz | to 0.85 kHz, |
| band 4 | from 0.85 kHz | to 1.25 kHz, |
| band 5 | from 1.25 kHz | to 1.55 kHz, |
| band 6 | from 1.55 kHz | to 3.15 kHz, |
| band 7 | from 3.15 kHz | to 6.35 kHz, |
| band 8 | from 6.35 kHz | to 16.5 kHz. |

Figure 4 compares relative AE signal energy emitted in individual bands during measurement in a four-ball friction pair lubricated with the oil RL 144/4. Bands 1 and 2 of the lowest frequency, regarding big objects (friction machine)

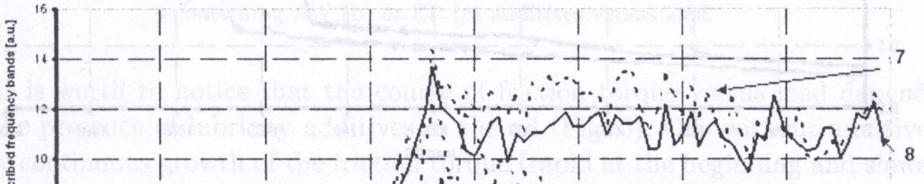



FIG. 4. Comparison of relative energy of AE signal generated in the four-ball friction pair lubricated with reference oil RL 144/4 at the speed of continuous load increase equal to 40 N/s; numbers in the diagram refer to the frequency bands.

vibrations are omitted because they do not give information on the friction pair. To compare easily the obtained results, a so-called relative signal emission was applied. It means a product of emission in a given band multiplied by mean emission in the same band at low load of the friction pair – below the scuffing load (from 100 to 300 N). Numbers in the diagram refer to the bands. It can be seen that exceeding the scuffing load causes the greatest AE energy changes in bands 7 and 8, that is for the frequency ranges from 3.15 to 6.35 kHz (band 7) and from 6.35 to 15.5 kHz (band 8). Also for oils containing AW and EP additives, bands 7 and 8 were the most favorable.

The next figure compares the friction torque at lubricating the friction pair with reference oil RL 144/4 without and with AW or EP additives (Fig. 5). Figure 6 compares relative energy of the AE signal generated during the same measurements in bands 7 and 8.

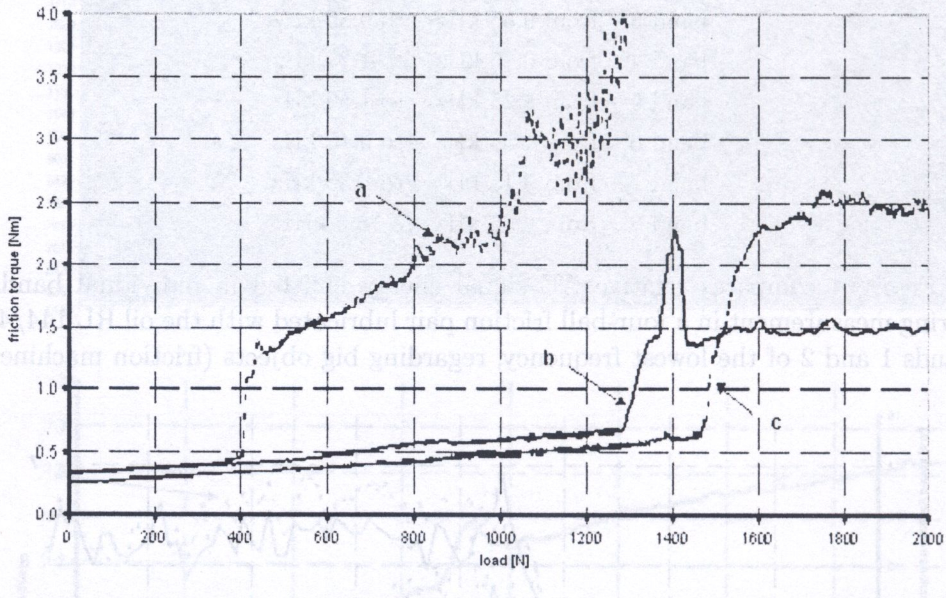



FIG. 5. Friction torque versus load for the four-ball friction pair lubricated with reference oil RL 144/4 without additives (a) and the same oil containing AW (b) or EP (c) additives.

Figure 6 presents only a part of relative energy courses – near the scuffing load – for the investigated oils. Significant difference between AE signal courses for the oil without additives (Fig. 6a) and the one containing AW or EP additives (Figs. 6b and 6c) can be easily noticed. However, the course of friction torque versus load does not show similar difference. Both the applied methods give the same values of the scuffing load (405 N – for the oil RL 144/4 without additives, 1290 N – for the oil RL 144/4 containing AW additive and 1470 N – for the oil

RL 144/4 containing EP additive), but they differ from each other in the ease of scuffing load detection. In the case of pure reference oil, detection of this point using AE analysis can be easier than applying the torque measurement. It results from the fact that in the investigated bands, the AE energy multiplies by 10 for loads exceeding the scuffing load, whereas friction torque multiplies only by 3 (Fig. 5a). For oils containing lubricity additives this point can be more easily detected by friction torque measurements by the described conditions (Figs. 5a and 5b).

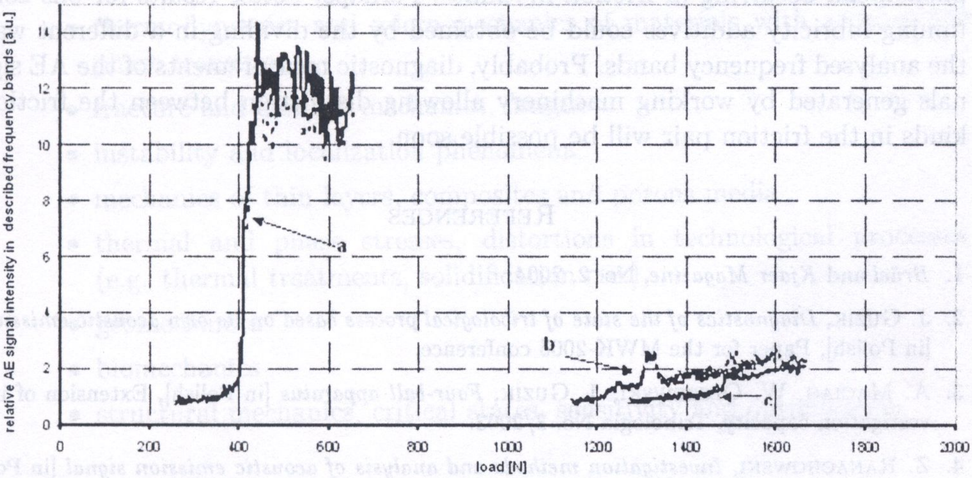



FIG. 6. Relative energy of AE signal in bands 7 (full line) and 8 (broken line) in the four-ball friction pair lubricated with reference oil RL 144/4 without additives (a) and the same oil containing AW (b) or EP (c) additives versus load.

It is worth to notice that the course of friction torque versus load depends on the presence of lubricity additives in the oil (Fig. 5). Oils without additives show continuous growth of the friction torque (rapid at the beginning and slower later). AW additives cause the occurrence of a peak (rapid growth and decrease) whereas EP additives cause rapid growth and slow decrease of the friction torque. This can be useful at oil evaluation. Modern engine oils show friction torque courses similar to those obtained for AW additives, whereas in the case of gear oils the courses are similar to those obtained for EP additives.

## 4. Conclusions

AE signals generated in friction pairs are relatively weak. For this reason, AE measurements require high quality accelerometers, filters of extraneous noise, amplifiers and software allowing processing of the registered results. Results presented in this work encourage to apply the AE measurements in investigation of working machinery friction pairs. It seems to be possible now to investigate the friction pairs lubricated with oils without additives (or containing small quantities of additives), for instance – with machine oils etc.

It was stated that small amounts of anti-wear additives in oil can be detected by applying the AE measurements [2]. Changes in the diesel fuel lubricity properties caused by the presence of additives can also be detected in AE measurements, what was stated earlier during realisation of this project [6].

Further investigation on AE signals seems to be necessary to explain the phenomena occurring in friction machines. Perhaps, better results for oils containing lubricity additives could be obtained by the dividing in a different way the analysed frequency bands. Probably, diagnostic measurements of the AE signals generated by working machinery allowing distinction between the friction kinds in the friction pair will be possible soon.

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